

Frequencies for Mars Local High Rate Link

David Hansen and Miles Sue
NASA/Jet Propulsion Laboratory
September 20, 2002

1.0 Introduction

Current Mars missions use the UHF band for local links between landers, rovers and orbiting spacecraft. UHF equipment has been designed for these links for relatively low data rates (8 to 512 kbps). The links typically use wide beam, low gain antennas that do not require active pointing control. There is a desire to provide for higher data rate local links for future missions. These links will require more bandwidth and higher EIRP and G/T values. The higher gain antennas will be more easily realized at a higher frequency than UHF. This paper looks at the options for frequency bands for higher rate links for the next five to ten years.

2.0 Bands of Interest

Several different bands have been considered: S-Band, X-Band, Ku-Band and Ka-Band.

S-Band is attractive because of the availability of commercial components, the existing frequency allocations for Near Earth and Deep Space and because it could be used without interfering with most future deep space missions which will primarily use X-Band or Ka-Band for their direct to Earth (DTE) links.

X-Band is attractive because of the existing Near Earth and Deep Space frequency allocations and because on board hardware could be shared for both the deep space and local links. The biggest concern is potential self-interference during simultaneous DTE and local link communication passes.

Ku-Band is attractive because of the availability and technology maturity of components from the commercial satellite industry and because it will not cause any interference with the DTE links. Close to the commercial satellite band there is a band at 15 GHz allocated to Space Research Service (SRS) downlink and another band at 16 GHz allocated to SRS uplink.

Ka-Band was briefly considered. It provides a very high bandwidth and potentially a large EIRP and G/T but it requires fine antenna pointing control making this appear to be a less viable option at this time. Also, there is not the hardware maturity and availability of the other frequency bands.

3.0 Considerations for Selecting a Higher Frequency Band

In determining the best option for a frequency band for higher data rates several requirements/desirements are considered. They are as follows:

- A) Feasibility of sharing (or reuse) of existing on-board equipment. This would include using some or all of the transceiver/transponder, power amplifier, diplexer and antennas on the spacecraft (both the lander and the orbiter) for both the DTE link and the local link. This is highly desirable from the project point of view because it would provide for a reduction in mass and cost.
- B) Support of Near Earth testing. Many missions desire the ability to conduct an in-flight test of the local link hardware on spacecraft when they are still close to Earth. This provides confidence that the hardware will work when it is on station. It also serves as an in-flight calibration. Frequently, future missions are relying on the just launched spacecraft for communications support during their landed mission. Getting early assurance that the hardware works and how well can shape the design of the next spacecraft.

- C) Compatibility (no interference) with the DTE spacecraft frequency. The concern is that the on board transmitter can cause self-interference between the local link and the DTE link. The spacecraft transmission in the same band could overwhelm its own receiver and preclude receiving an intended signal. A lesser concern is that a nearby spacecraft at Mars, while communicating to Earth, can interfere with the local link. Providing sufficient filtering to overcome the interference might cause too much insertion loss to be practical.
- D) Technology maturity and hardware availability. In choosing a band for the local link it is important to consider the availability of components for designing and fabricating the hardware.
- E) Approaching spacecraft navigation. A new goal for future orbiters is to provide a capability to perform radio navigation for incoming spacecraft from an orbiting Mars spacecraft. This would be performed at the incoming spacecraft's DTE frequency.

4.0 Analysis of Requirements for Frequency Selection

A. The first issue is the feasibility of sharing the equipment for both the DTE and local links. X-Band and Ka-Band are the deep space bands of choice for future missions. Ka-Band was previously considered for the local links but has not been pursued further because of the difficulty in pointing the antennas. While this limitation can be overcome by advanced antenna technology in the future, this leaves X-Band as the choice for sharing hardware, at least for the near term.

For an X-Band local link, the existing Deep Space spectrum could be used. This would allow for using the current DTE transponders for the return link. From a spectrum point of view, using the Near Earth spectrum (7190 – 7235 MHz, Earth-to-Space; 8450 – 8500 MHz, Space-to-Earth) would be better – no interference with other spacecraft at Mars. The Near Earth band is adjacent to the deep space spectrum (7145 – 7190 MHz and 8400 – 8450 MHz). The current deep space allocation is crowded. Using the Near Earth band for the local link would allow for sharing the X-Band power amplifier, diplexer and antennas. All of these devices should be able to cover the expanded bandwidth. The current transponders are not frequency agile and would not work in the Near Earth spectrum. Also the modulation scheme for the uplink is much different than the local link would use. A future transceiver/transponder might be able to accommodate both the DTE and local link modulation schemes and radio navigation signals. Another possibility is to add a capability to the local link transceiver (now operating at UHF) to allow it to receive/transmit X-band signals via the DTE X-band antenna and front end. Either way there would be a great reduction in hardware with the benefits of reducing mass, simplifying the design and lowering overall cost.

The effect would be significant for a landed spacecraft. A rover or lander is always mass and power limited. It is unlikely that there would be sufficient power for simultaneous links back to Earth and to a local orbiter. The lander could support a very high data rate back to an orbiter with a small HGA and a moderate size X-Band power amplifier, like the MER rovers have. (MER uses a 0.28m X-Band HGA with a 15W X-Band SSPA.)

The orbiter will not really get the advantage of sharing hardware because the local link will be at the reverse frequencies of the DTE link. It may be able to share some antennas depending on the spacecraft design and attitude. The orbiter is no worse off than using a non-shared frequency.

B. The next desire is support of Near Earth testing. The Mars Odyssey spacecraft is flying a UHF local link payload for support of future landed missions. The Mars program requested that the equipment be tested post-launch in support of the MER 2003 rover mission, which will rely on Odyssey for much of its data return. MER wanted to be confident that the UHF equipment was working to maintain their current mission design. Testing the UHF equipment in flight is problematic because the band is allocated for other services. JPL had to overcome many hurdles to support the in-flight testing and it may be even more difficult to perform this type of testing in the future. Testing the downlink is not really an issue because the received

power from Odyssey is so low. The real concern is a high power uplink which could interfere/damage a satellite with a UHF receiver.

In deciding on a new band for a high data rate local link, it would be better to choose one with an existing Deep Space frequency allocation so as not to intrude on other bands when conducting in-flight tests. S-Band and X-Band are the two choices. They have existing allocations. Ku-Band would be a possibility for the future when the rate requirements increase.

The alternative to performing in-flight testing with a ground station is to have the spacecraft carry an on-board self-test capability. This can test the local link electronics but not the complete system including the antenna. The Deep Impact mission has an on-board self-test capability because it is carrying both halves of the radio link before release of one of the spacecraft just prior to encounter. The Electra UHF radio that NASA is developing will have some form of self-test capability as well. The receive capability of the spacecraft's local link can be tested with a CW carrier signal from the ground. This would prove to be much less of a problem on an interference basis than transmitting wideband data. If the local link has a frequency agile transceiver, an uplink carrier can more easily be chosen that will not interfere with local users.

There are two different scenarios for Near Earth testing if S or X-Band is used. The landed element and the orbiter will have reverse frequency pairs for the uplink and downlink. The landed element can test most of its local link hardware within the existing deep space (or Near Earth) allocated spectrum. At X-Band the landed element will transmit at 8.4 GHz and receive at 7.2 GHz. The orbiter will have the reverse – transmit at 7.2 GHz and receive at 8.4 GHz. To test the orbiter's local link hardware, the mission would have to request a waiver to operate out of band in the Space Research Service, but that assumes that there is ground hardware which could interface with these frequencies. A simpler solution is to perform on-board self-testing between the DTE link hardware (7.2 up and 8.4 GHz down) and the local link hardware (8.4 GHz up and 7.2 GHz down). If one of the transceivers is frequency agile to cover the whole band, this should be easily accommodated.

C. The third issue is compatibility with the existing DTE equipment. The main issue is self-interference during simultaneous DTE and local link communications. If the local link frequency is at S-Band or Ku-Band then there is no problem. These frequencies will not interfere with the DTE link, because all known Mars missions use X-band for the DTE link, although some also use S-band. This is an issue if both the local link and the DTE link are in the same frequency band, e.g. X-Band. Even if the local link is in the Near Earth allocation and is 50 MHz away from the DTE channel, the power from the transmitted signal can saturate the front end of the receiver. This signal would then capture the receiver, preventing reception of the intended signal. This is the case for very strong signal interference. Figure 1 presents a diagram showing an example of this type of self-interference. If the interference is not too strong, such as the case when the interfering signal is from another spacecraft, then the receiver front end can pass both the desired signal and interference, and filtering at IF can filter out the unintended signal. Figure 2 shows this scenario.

Self-interference is not a concern for a landed element. It is unlikely that the landed element will have sufficient power to support transmitting both the DTE link and the local link simultaneously. In addition, its sequence can be planned to preclude this from occurring.

The concern is for an orbiter, which is simultaneously communicating with Earth and a landed element. There are two possible scenarios for interference: transmitting to the Mars surface and receiving from Earth (at 7.2 GHz) and transmitting to Earth and receiving from the Mars surface (at 8.4 GHz). The first option may not be allowed. Some missions may choose to not transmit from an orbiter to a landed element at 7.2 GHz. Doing so could prevent both the orbiter and lander from receiving commands from Earth. This is true for the orbiter because of self-jamming and for the lander because its receiver is locked to the orbiter's forward link. These missions may choose to have the forward link from the orbiter to the lander at UHF, but this requires having UHF equipment on board. If the mission chooses to have the orbiter – lander forward link at 7.2 GHz, the resulting interference problem can be solved through operational coordination or planning. Depending on the orbiter's trajectory, the possible interference time could be relatively short.

Filtering could be employed to reduce the signal from the transmitter going into the receiver front end, but the receiver would suffer from a large insertion loss (5 – 10 dB). This might be acceptable for the local link because it may have very large margins, even for high data rates. But this would clearly be unacceptable for the deep space link. A simple solution, achieved operationally, is to not support simultaneous communications for the two links.

Depending upon the communication orbiter's trajectory, it will not really see the landed element for that much time per orbit. Ceasing communications to Earth during this brief outage would not significantly impact the mission, although this will complicate mission operations.

The alternative is to choose S-Band or Ku-Band for the local link. They will not interfere with the DTE link, most likely X-Band. Of course if the DTE link is Ka-Band then there is no issue for any of the possible frequency choices. This assumes use of a Ka-Band uplink or no X-Band uplink during local link communications.

D. The fourth factor to consider is the availability of hardware in the respective bands. S-Band and Ku-Band are both popular commercial bands. X-Band is currently used on many deep space spacecraft. All of these are active bands and the availability of components should not weigh heavily in deciding the best option for a high rate Mars local link frequency band.

E. The last desire is support of approaching spacecraft navigation. This would require that the orbiter have the capability to receive at the incoming spacecraft's DTE frequency, presumably 8.4 GHz. For now, this is envisioned as a one-way link. The approaching spacecraft would require a decent oscillator to provide reasonable Doppler data.

F. Other Issues

Performance: S-Band is not that much higher in frequency than UHF. It requires a sizable antenna to achieve the necessary gain to overcome the increased space loss at S-Band. The improvements in EIRP and G/T will be greater at X and Ku-Band without requiring precise antenna pointing. The MER rovers will have an X-Band EIRP of about 62 dBm and a G/T of –10 dB/K. Typical UHF values are an EIRP of 40 dBm and a G/T of –27 dB/K.

Mars Coverage: One of the downsides of increasing the frequency is that the antenna beam from the orbiter down to the surface will be smaller. The antenna will not cover the entire Mars disk. This precludes the possibility of having simultaneous return links from the surface.

Evolution: Figure 3 shows the current frequency scheme for Mars local links. The orbiter uses X-Band up and down for its DTE links. The lander has X-Band DTE links. The local link is done at a single UHF frequency pair. Figure 4 shows a possible next step in the frequency scheme at Mars. The orbiter uses X-Band and Ka-Band for the DTE links. The lander has an X-Band DTE link. The local links are done at UHF with high rate X-Band (either the deep-space X-band or the near-Earth X-band) links. A possible far future frequency scheme is shown in Figure 5. It shows that orbiter using X-Band up and Ka-Band down for its DTE links. The landed element uses X-Band up and down and Ka-Band down for its DTE links. The local links use separate Ku-Band equipment to support high rates for both the forward and return links.

5.0 Recommendations

Based on the above discussion, the recommendation at this time is to use the Near Earth X-Band allocation for the high data rate local link frequency. Using this band would provide a much wider bandwidth for high rate communications. It would allow for re-using DTE radio equipment for a reduction in mass and cost. It would provide for greatly improved data throughput performance. It would not interfere with other spacecraft operating in the X-Band Deep Space frequency band. It also provides a better solution for performing Near Earth in-flight testing post launch on a non-interfering basis.

The biggest downside to using X-Band is the potential self-interference issue. This could be overcome with filtering at a cost of increased insertion loss into the local link receiver on the orbiter. The simplest solution is to avoid simultaneous DTE and local link communications.

The best option for a high rate local link is to fly landers and rovers that work at X-Band for both DTE and local link communications and to fly orbiters that are dual frequency - X and Ka-Band capable. The orbiter can use X-Band for cruise and emergency communications and Ka-Band for high rate science and relay data return at Mars. The orbiter should have a frequency agile X-Band capability to receive data from and transmit to the Mars surface. The orbiter would then be able to support simultaneous X-Band local link communications and a high rate Ka-Band downlink to Earth.

The research described in this publication was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.



Self-Interference (internal EMC) :X-X

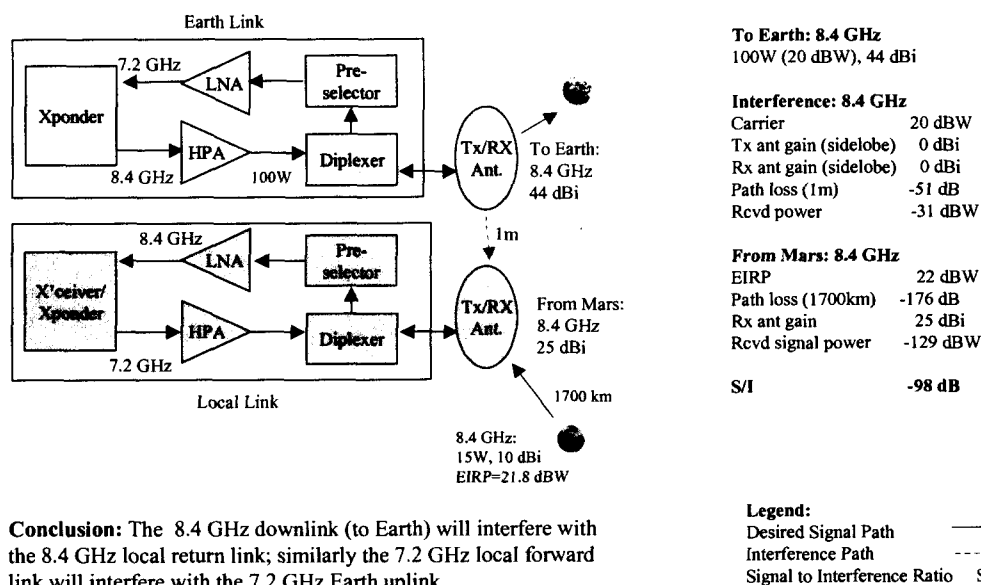


Figure 1. An illustration of self-interference (internal) when transmitting and receiving in the same frequency band



Inter-Satellite (External) Interference:X-X

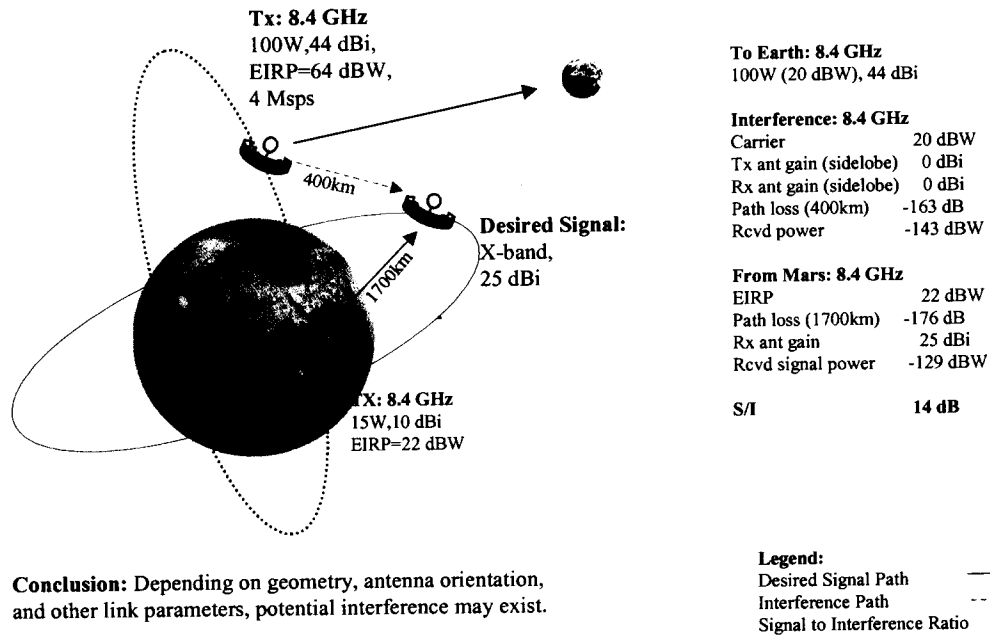
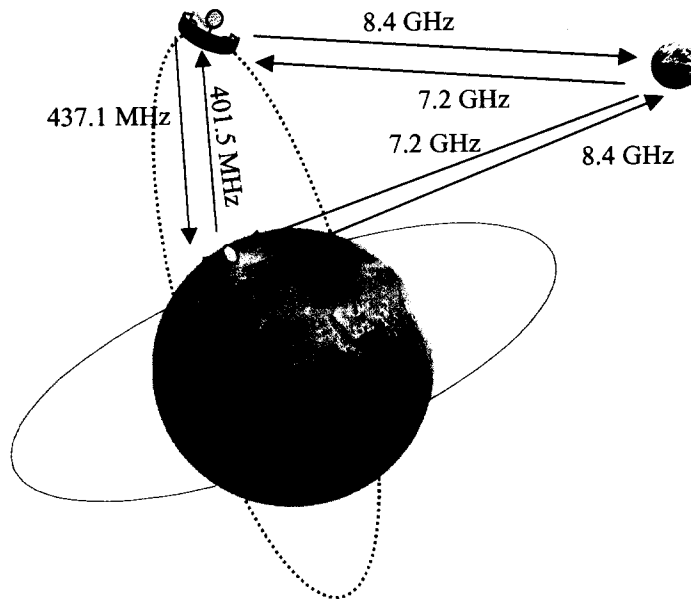


Figure 2. An illustration of external (inter-satellite) interference when the same frequency band is used for



Mars local links and DTE links

Figure 3. Current Frequency Scheme at Mars: X-Band DTE links and UHF local links

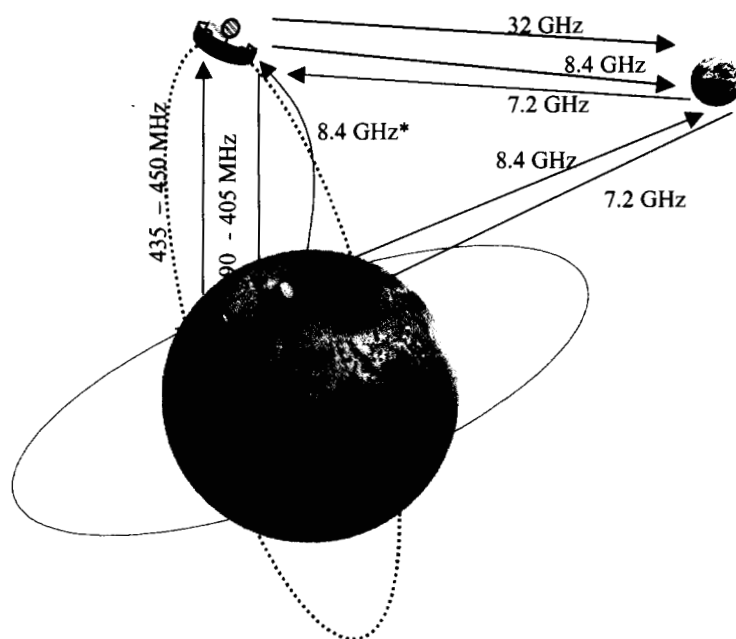


Figure 4. Near Future Frequency Scheme at Mars: X-Band and Ka-Band DTE Links, UHF and X-Band* local links (* either the deep-space X-band or the near-Earth X-band)

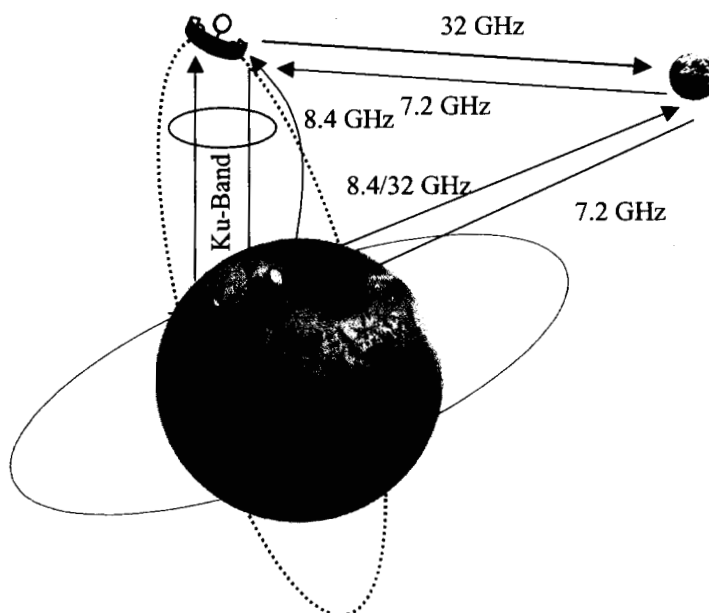


Figure 5. Potential Future Mars Frequency Scheme: Uses X and Ka-Band for DTE links and a dedicated Ku-Band high rate local link (Mission may continue to use UHF for low rate links)